TEMPERATURE AND VOLTAGE DISTORTION ANALYSIS IN LED LAMPS

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ABSTRACT

Measurements in electrical and thermal parameters of LED lamps over time have been studied. To get comparable results between lamps, for compliance testing and benchmarking, measurements after stabilization are recommended. Two cases have been tested in the lab: stabilization with sinusoidal voltage waveform and stabilization with distorted voltage waveform both with and without external cooling of the lamp, giving four tests for each LED lamp.

The parameters tested were illuminance, active power and temperature of the LED lamps. Based on the results for voltage variations, no significant difference of the parameters studied have been observed. On the other hand, according to the results about environmental thermal variations (emulated using forced ventilation) it is concluded that the illuminance increases with low temperatures, and in addition, in greater percentage than the active power consumed, since the low temperatures would decrease the temperatures of thermal stabilization of LED lamps.

INTRODUCTION

Characterized by their low consumption, good illumination efficiency and high durability, LED lamps are currently extended for many applications in domestic use as well as in street lighting. However, optical characteristics, reliability, and lifetime strongly depend on temperature in LED lamps [1], [2]. In fact, the manufacture indicates how the parameters are affected by the temperature variation. There have been many reports about early failures of lamps that have been seen as a barrier in the public acceptance of LED lamps [3]. Therefore, temperature is always a crucial issue for LED product development. When testing a device, regardless of the aim being time of failure, light output quality or some power quality index, it is important to eliminate uncertainties affecting the reproducibility of the tests. These uncertainties can be e.g. variations in voltage feeding the lamp or variations in the ambient temperature during the measurement. To achieve better reproducibility when measure LED lamps it is recommended to allow the lamp to burn for a certain amount of time, i.e. until it is considered stable. In [4] it is showed that the temperature of an 80 W LED street lamp is stabilized only after an operation time of several hours. Similar results were found in [5] with a 114 W LED street lamp. The aforementioned studies only considered the thermal characteristic of the LED lamps without considering neither light output nor electrical quantities.

In another study [6], the lamps were subjected to rectangular modulated voltage variations for immunity testing. Although the focus of this study was rather immunity testing, the sufficient stabilization time was indicated between 10 min. and 15 min. depending on the lamp.

Moreover, the purpose of [7] was to analyze the variation in the light intensity during thermal stabilization of the LED lamps, showing that it decreases with time, recommending at least 60 minutes measurement with residential LED lamps. However, only the illuminance was used as a parameter to determine the thermal stabilization of the lamps. Here, it is extended to give a method using also power and temperature. Based on that, the idea of the current paper is to show that the thermal stabilization time varies between lamps and test condition, as well as to determine a proper method and appropriated parameter to be used for finding at what point the lamps is considered stable.

MEASUREMENT SETUP

Communications

To synchronise the data acquisition of the light output, voltage and current, the Yokogawa DL850E oscilloscope and Keysight Technologies Programmable Single phase Voltage Source 6811B have been connected by Ethernet and GPIB command respectively, controlling both instruments trough LabVIEW NXG 1.0.2 and VISA ports as Figure 1 shows.

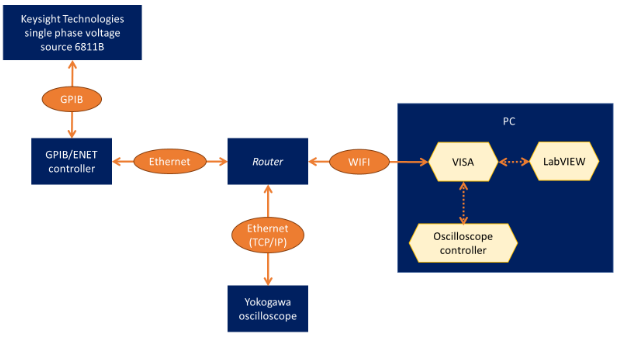

Figure 1. Connections and communications implemented in the platform.

Test Platform

The platform is composed by a wooden base where a cap has been set to keep constant distance between the studied lamp and the other devices, and a paperboard box which encloses the LED lamps to avoid light disturbances during the measurements. The platform contains the sensor of the luxmeter E4-X from Hagner (Resolution: 1 lux/mV), the thermal camera Ti45FT from Fluke (emissivity: 0.95, lens: 20 mm, focal relation (F): 0.8) and the fan 3610KL-05W-B50 from Minebea Mitsumi (Source: 20 V CC).
The Yokogawa DL850E oscilloscope measures, with three channels, voltage (analog module 701267: speed 100kS/s and 16-Bit), current (measurements from the Pearson current probe and acquired with the voltage analog input module 701251: high speed of 1MS/s and 16-Bit) and light output (another channel from the module 701251), all synchronized. The thermal camera records the temperature. The distribution of the devices is shown in Figure 2.

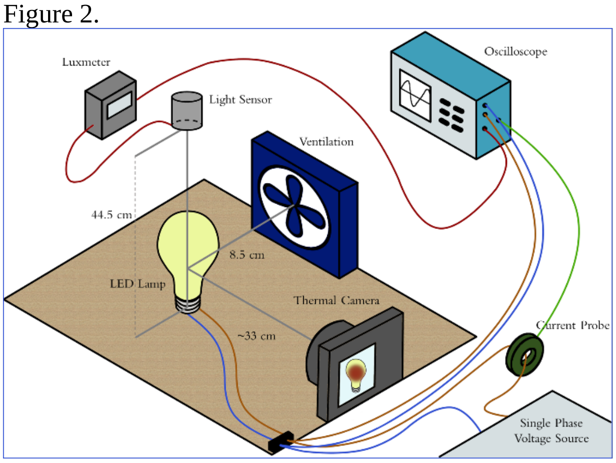

Figure 2. Test Platform overview.

LED lamps tested

The list of LED lamps tested is given in Table 1. LED lamps currently available in the Spanish market have been tested within a period of 90 minutes. Four different brands have been chosen, the power varies from 5 W to 12 W. The total quantity of the illuminance emitted by the lamps varies from 350 lm to 1055 lm.

TABLE 1. Data of Tested Lamps, provided by the manufacturer

LED number	*Power (W)*	*Lumens (lm)*	*Colour temperature (K)*
LED 1	6	470	2700
LED 2	9	806	2700
LED 3	7	470	2700
LED 4	8	806	3000
LED 5	8	470	2700
LED 6	12	806	2700
LED 7	10	1055	4000
LED 8	9	-	6000
LED 9	5	350	4000
LED 10	6	400	3000

METHODOLOGY

Supply voltage has been 230 V, 50 Hz and the temperature in the laboratory has been kept at 24ºC. The acquisition frequency of the oscilloscope was set to 1 MS/s with a 0.2 s window as recommended by IEC 61000-4-30 standard.
To observe the impact of the distortion of the supply voltage in the stabilization of the lamps, the following measurements have been made:

- Sinusoidal voltage waveform, 230 V RMS.
- Distortion of the supply voltage with a modulation frequency of 5 Hz with an amplitude of 3% of the fundamental voltage (230 V).

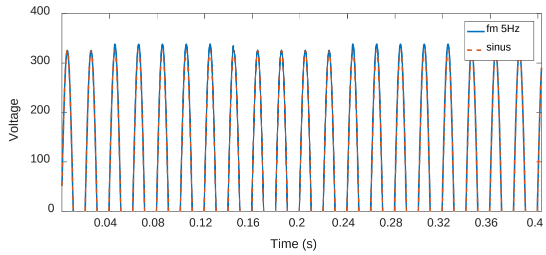

Figure 3. Supplied voltage considered.

These two measurements have been made, both with the fan on and off to see the ambient temperature influence on the illuminance and on the active power, two factors that define the efficiency of the lamps.
Voltage, current, temperature and light output have been measured from t=0 to t=90 min, taking one sample every 10 minute and the time and temperature dependencies have been studied. Data has been taken every 10 minutes as the temperature has a slow dynamic.

RESULTS

Temperature, active power and illuminance evolution over time has been considered in this section. This trend has been plotted as a percentage of variation between two consecutive instances according to equation 1, where X is temperature (ºC), active power (W) and illuminance (lux) respectively in every case study. Positive values indicate that the value of the variable has increased from one instant to another and its absolute value indicates the percentage of variation.

$$\Delta X\ (t_n) = \frac{X(t_n) - X(t_{n-1})}{X(t_{n-1})} * 100 \qquad (1)$$

Temperature variation

As was shown in [7], the light intensity in LED lamps decreases with time until a level that can be considered as steady state after switching on. The thermal stabilization time t_s is defined as the lowest value of t_n for which the following inequality holds:

$$\Delta T(t_n) \leq 1\% \qquad (2)$$

To the aim of this study, the threshold for the temperature variation has been set to 1% as it implies 1ºC variation.

To start with, the LED lamp sample was connected to pure sinusoidal voltage waveform without a fan and the results are shown in Figure 4. Due to the difference in vertical scale between the first sample and the following, the first sample of this variation in temperature has been removed from Figure 4 (t_1-t_0). During the first 10 minutes, the variation in temperature reaches the highest values (not shown here), ranging between 160% (LED 9) and 83.5% (LED 5 and 10), as some lamps dissipate initially better the temperature than others as they use different heat sink technologies. As can be seen, all LED lamps increase in temperature with time (positive percentage of variation), however the difference in temperature varies between lamps. The percentage of variation between 20 to 10 min (first sample shown in Figure 4) varies between 23.7% (LED 6) and 11.5% (LED 7). This difference in variation between lamps decreases, reaching 2% after 50 min.

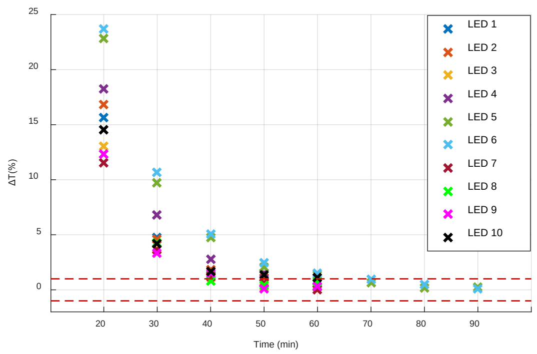

Figure 4. Temperature variation (%) of different LED lamps connected to pure sinusoidal 230 V RMS without fan cooling the lamps.

As was previously defined, the thermal stabilization time t_s is defined as the time when the temperature variation is lower than 1% (red dotted lines). The variation at minute 60 is 1% or below for 70% of the lamps tested (the other reaching 1.5% variation as maximum). The thermal stabilization time from this temperature study is similar to the one found in [7] measured over light intensity.

Only LED 5 and 6 did not reach strictly 1% at minute 60, so that, they were measured longer time. In these cases, the difference between temperature at minute 70 compared to minute 60 was 0.98% and 0.66% respectively, so that, both lamps are considered to be below 1% from minute 60 to 70.

In order to know how external temperature influences the thermal evolution in the LED lamps (i.e. when LED lamps are subjected to cooler ambient temperatures where they are located), the same test was repeated (pure sinusoidal voltage waveform) with a fan cooling the lamps, reducing the temperature with approximately 25% to 40%. The LED temperature was measured every 10 min (from t=0 to t=90 min). Figure 5 shows the temperature variation according to equation (1) without plotting the first sample (t_1-t_0) as in Figure 4. The effect of cooling the lamp is visible in all samples, the variation in temperature reaches again the highest values in the first 10 min (not shown here), ranging between 101% (LED 9) and 50.5% (LED 10), but lower than the difference reached when the fan was no connected.

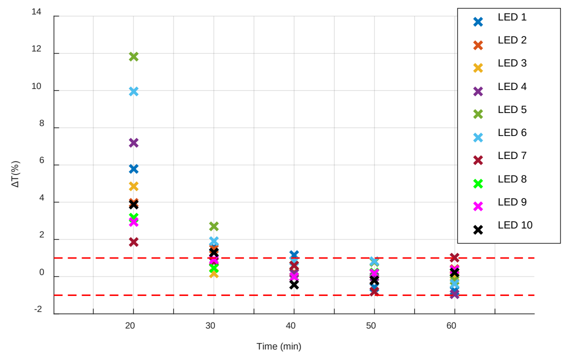

Figure 5. Temperature variation (%) of different LED lamps connected to pure sinusoidal 230 V RMS with fan cooling the lamps.

In the second sample (from 20 to 10 min), the variation in temperature varies between 11.8% (LED 5) and 1.9% (LED 7). This difference between lamps decreases even more leading to a shorter thermal stabilization time (for most lamps ts=40 min) compared to the previous case without fan.

The other effect considered is the temperature stabilization study when lamps are connected to a distorted voltage waveform (as shown in Figure 3). With this test, the temperature dependency with the voltage fluctuation will be studied without (Figure 6) and with (Figure 7) a fan cooling the lamps.

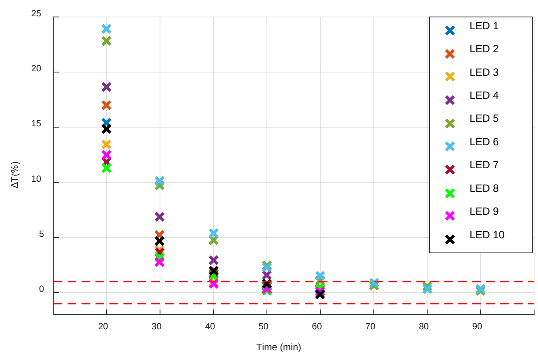

Figure 6. Temperature variation (%) of different LED lamps connected to 5 Hz sinusoidal voltage fluctuation without fan cooling the lamps.

In the case shown in Figure 6, the temperature variation with modulation frequency is similar to the result obtained when lamps were connected to pure sinusoidal voltage waveform (Figure 4) both without fan cooling the lamps, and the stabilization time can also be considered to be 60 min from this study. The distortion in the voltage waveform has no significant effect in the thermal stabilization, as it also takes 60 min to be stable in this case.

The effect on cooling the lamp with the lamps connected to a distorted voltage waveform is shown in Figure 7. This case shows some similarities with the case of the lamps connected to a sinusoidal waveform while cooled by the fan (cf. Figure 5). In the second sample (from 20 to 10 min), the variation in temperature varies between 11% (LED 5) and 1.9% (LED 8). At this instant, most of the lamps have the same decrease in temperature independently of the supplied voltage, but LED 8, as it decreases in temperature more with pure sinusoidal (3.2%) than with distorted voltage (1.9%). Similar behavior takes place in the other instants.

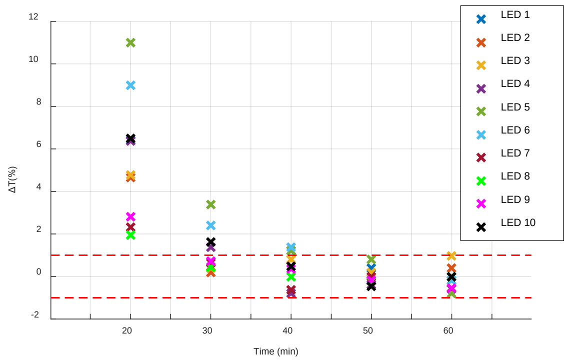

Figure 7. Temperature variation (%) of different LED lamps connected to 5 Hz sinusoidal voltage fluctuation with fan cooling the lamps.

The difference between lamps decreases even more during the following samples leading to the same thermal stabilization time (40 min for almost all lamps) compared to the previous case (pure sine) without fan.

Active power variation

As it was stated at the beginning of this section, the active power evolution with time has been plotted as a percentage of variation between two consecutive instances according to equation 1. Due to similarities in the active power variation between results with and without cooling the lamps, only lamps connected to pure sinusoidal voltage waveform without fan are presented here. As it can be seen from Figure 8, all the lamps (except LED 2) decreases in active power with time (negative percentage of variation) as was already shown in [7] and [8]. To know the stabilization time according to active power, the variation in active power might be considered $\geq -1\%$ in the inequation (2). According to that, the stabilization time is 30 min for this set of lamps.

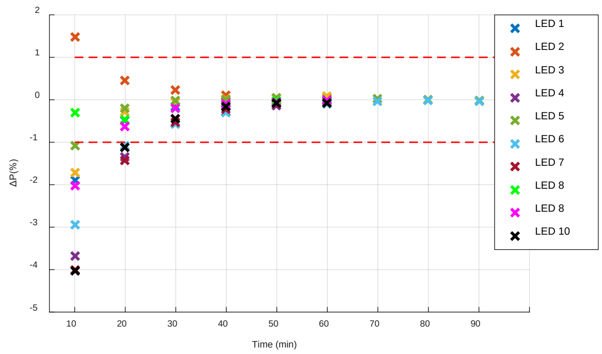

Figure 8. Active power variation (%) of different LED lamps connected to pure sinusoidal 230 V RMS without fan cooling the lamps.

Illuminance variation

Similar to previous cases, the LED lamps illuminance evolution with time has been plotted as a percentage of variation between two consecutive instances according to equation 1.

As with active power, all the LED lamps decrease in illuminance with time, as shown in [7]. To know the stabilization time according to illuminance, the variation in illuminance might be considered $\geq -1\%$ in inequation (2). According to that, the stabilization time for these lamps is 40 min. LED 5 has however reached a stable condition already after 20 min.

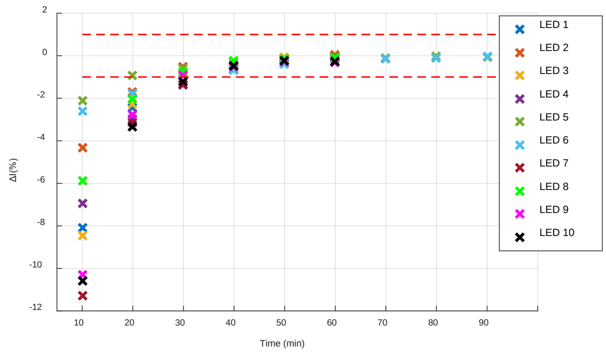

Figure 9. Illuminance variation (%) of different LED lamps connected to pure sinusoidal 230 V RMS without fan cooling the lamps.

DISCUSSION

Impact from change in ambient temperature

All the comparisons in this section have been done when the LED lamps were stable (after stabilization time) and connected to pure sinusoidal voltage waveform.

Figure 10 represents the change in illuminance and active power when the LED are cooled with an external fan. It follows equation 3, where X is active power (W) or illuminance (lux) accordingly.

$$\Delta X = \frac{X_{fan} - X}{X} * 100 \qquad (3)$$

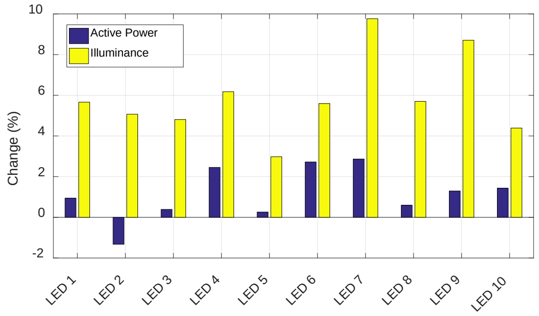

Figure 10. Active power and illuminance variation when LED lamps are connected to pure sinusoidal voltage with and without fan.

Cooling the lamps leads to an increase in illuminance for all the lamps. The variation in the illuminance varies between 3% and 10%. Moreover, cooling the lamps leads to an increase in active power for all the lamps (except LED 2). The variation in active power is lower, and it varies between 0.3% and 3%, so that, the active power is less sensitive to cooling the lamps than the illuminance. The greatest impact is seen for LED 7, the absolute temperature difference between the two cases is around 35%, and this gives a change in active power of 3% and change in illuminance with 9.8%.

Impact from voltage distortion

Figure 11 represents the variation in the active power, temperature and illuminance when the LED lamps were connected to 5 Hz sinusoidal voltage fluctuation compared to sinusoidal voltage waveform following equation 4, where X is active power (W), temperature (ºC) and illuminance (lux).

$$\Delta X = \frac{X_{fm} - X_{sine}}{X_{sine}} * 100 \quad (4)$$

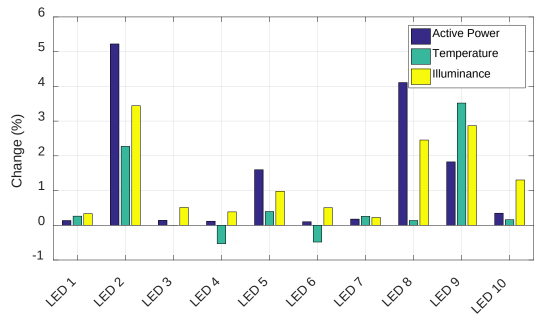

Figure 11. Active power, temperature and illuminance variation when LED lamps are connected to 5 Hz sinusoidal voltage fluctuation compared to sinusoidal waveform.

All the lamps show a small increase in active power and illuminance when connected to 5 Hz sinusoidal voltage modulation compared to pure sinusoidal, but the difference varies between lamps even more than the effect seen when cooling the lamps.

CONCLUSION

The stabilization time according to temperature evolution presents the longest time (60 min), while according to light output and the active power the lamps reach before the stabilization time (30 and 40 min respectively). For this reason, thermal stabilization is considered the reference to know when the LED lamp is stable before doing more measurements. It is also shown that the stabilization time differs for different ambient temperatures. As the LED lamps were sensitive to changes in ambient temperature this parameter should be kept constant during comparative tests.

As the illuminance increases more than the active power when the LED lamps are cooler, it is concluded that the LED lamps are more efficient at low temperatures. So that, efficiency in LED lamps changes depending on the weather conditions, as seasonal changes or the geographical area.

As results show, a variation in the sinusoidal waveform has different effects depending on the LED lamp studied. However, in all of them there are a slight increase in the active power and illuminance. More measurements over different voltage distortions at different frequencies will be included in further research.

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